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INTEGRATED DESIGN OF EXPERIMENTS JOBS

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Integrated Design of Experiments Jobs

Abstract

Production factories have the requirement to properly monitor and control the production process. Such process control in many cases requires printing several times a set of parts changing certain process knobs for each set of layers. Then, the parts are somehow measured, and based on the measurements some process knobs can be properly adjusted. There are other scenarios in which is required to define different experiments, either because it is required to adjust the process for a new material or printing profile, or because the process needs to be adjusted for a new hardware. To provide a solution for these scenarios, in this invention disclosure we propose an integrated method for designing and submitting Design of Experiments (DoE) jobs, properly estimating, and processing them and univocally capturing the data while printing.

Introduction

For adjusting the 3D printing process, it is usually required to perform a sweep of certain process knobs to identify the set of process knobs which provide the desired results. A common approach is to define multi-level jobs (i.e., jobs in which the same set of parts is repeated several times within the job height forming layers of parts), so that each level of parts is configured to be printed with a specific set of process knobs. This allows reducing the experiments execution time compared to printing each layer of parts as an independent job which is printed in a different printing session. However, currently there is no mechanism to provide the configuration for these DoE jobs.

Also, the problem is that the 3D Printer needs a mechanism to estimate the required resources (material, agents, etc.) prior to the printing of the multi-level job, to avoid running out of resources in the middle of the printing process. However, current mechanisms for estimations do not support having different configurations at different levels of the printing. In this invention disclosure we propose a method for estimating the ranges of layers and usage of resources (material, coalescing agents, etc.).

Proposed method

The idea is to allow specifying the levels and their parameters in the job ticket so that we can group all the experiment in a single job, and all the parts in a single 3MF file. The changes we are proposing in the Device API are mainly in two parts: in the definition of job ticket and in the reported information in the job summary.

Job Ticket changes

- Add a new Levels element in the Job Ticket sent in POST /jobs. This element will contain a collection of Level elements; each Level will provide the following data:

- ID. Unique identifier of the level, for traceability purposes. This identifier is assigned by the client application; even though it is not required to conform to any format, we highly encourage client applications to follow a well-defined approach when assigning those identifiers, e.g., 'level-1', 'level-2', etc.
- Start. The position in the Z-axis where the level starts. This is a {value,units} tuple so that the client application can use its preferred units.
- Height. The height of the level in the Z-axis, upwards from the Start position. This is optional; if not specified, the level continues until the end or until the next level starts. This is a {value,units} tuple so that the client application can use its preferred units.
- Coordinate System. Indicates whether the positions are specified in the Physical coordinate system or in the User coordinate system. See below some important considerations. Coordinate system considerations:
  - The Z-axis is positive upwards.
  - The origin of the Physical coordinate system is located at the bottom of the build bed.
  - The origin of the User coordinate system is located a certain number of layers above the build bed.
  - The Physical coordinate system units will be rounded to micrometers.
  - The User coordinate system is defined by the 3MF file and is affected by thermal compensations.
- Printing Profile. The printing profile to use for the level, including the profile parameters to use.

Job summary changes

- Information about the levels defined in the job ticket. That is, basically, a copy of the Levels element from the job ticket, but since this information is reported by the device, the following information can also be reported for each level:
  - An element LevelIndex with an index assigned to the level.
  - Additional elements could be added, but we need to understand better the use cases to ensure they are required. Here are some ideas (notice none of them are included in the XML schema yet):
    - An element LayerCount with the number of layers in the level.
    - An element FirstLayerIndex and LastLayerIndex indicating the indices of the first layer and the last layer included in the level.
    - An element PartCount with the number of parts in the level.
- Information about the level corresponding to each layer. Notice all layers are listed in the job summary, in the Layers element. So, we're saying that for each layer there will be a new optional element LevelIndex that will reference the level where this layer belongs. When not present, it will mean the layer does not belong to any level.
- Information about the levels of a part. Notice a part might cross level boundaries, and therefore it might be affected by no level, a single level, or even multiple levels. We'll be adding therefore a new element Levels in the part information reported in the job summary, which will be a collection of LevelIndex elements referencing the corresponding levels.

Considerations and limitations

Following are some important considerations and limitations:

- No level intersection. We won't support intersecting level definitions. A job ticket specifying intersecting levels will be rejected.
- Parameter precedence. We'll apply the following order of precedence to ensure there's a clear deterministic way of knowing which parameter value is applicable at each layer. For each layer:
    - Level parameters. If the layer is part of a level, the parameters specified for that level take precedence over any other.
    - Profile parameters. If the layer is not part of a level, the parameters specified for the profile take precedence over the defaults of the printer.
- Mandatory parameters. Because of the Parameter precedence rule above, notice that a mandatory parameter CAN be omitted by Level parameters.
- Level identifiers must be unique. A job ticket with the same identifier in multiple levels will be rejected.
- Layer boundaries. Print profile and parameter changes will only be triggered in layer boundaries.
- Layer thickness limitation. Layer thickness changes within a part will not be supported (3MF processing will fail).
- No level resource selection. No support for resource selection within each level.

Level definition examples

The following diagrams depict different scenarios:

- A job that defines a single level using Start and Height.

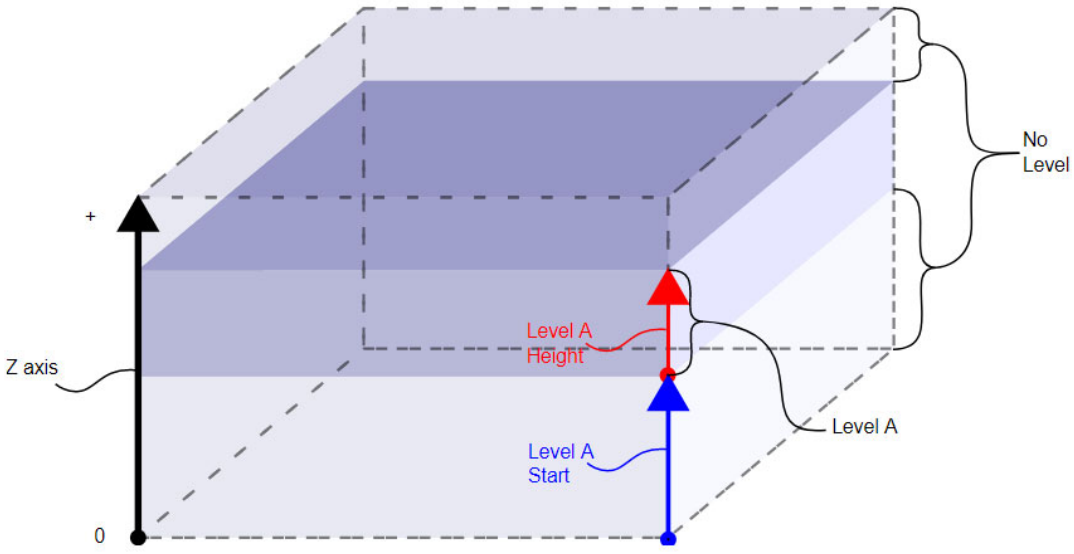

Figure 1. Single level using Start and Height

- A job that defines two levels, the first with Start and Height, and the second just with Start. See how there's a gap between the two levels.

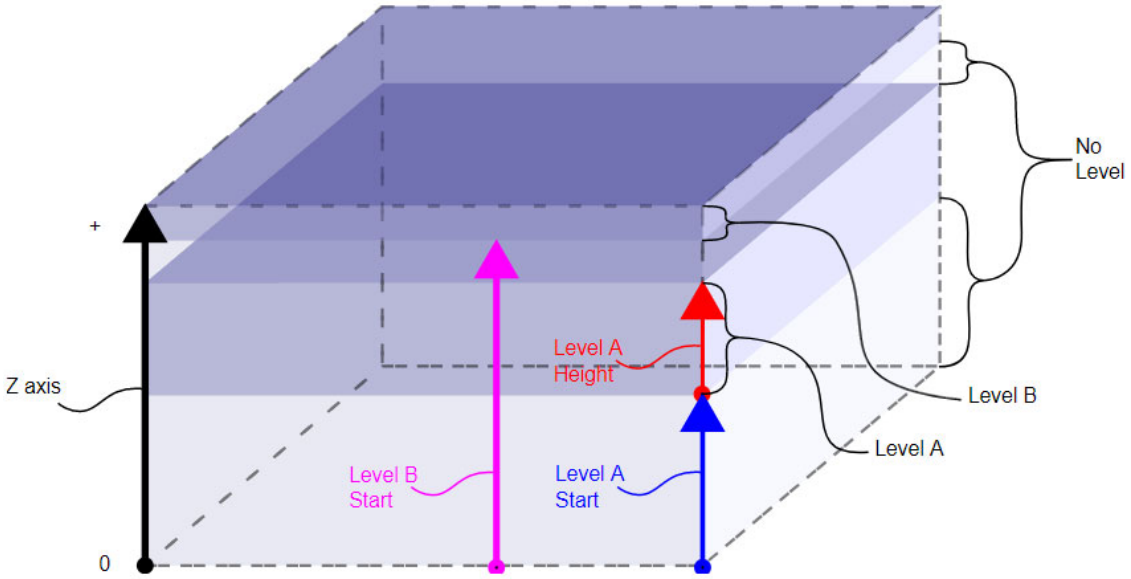

Figure 2. Job with two levels and a gap between them.

Estimating and Printing DoE jobs

Design of Experiments jobs allow to specify different layer ranges from the input job for which different printing profile parameters will be applied. The definition of these layer ranges can be done in two different coordinate systems, and there is the restriction that the definition of the layer ranges cannot mix layer ranges defined in different coordinate system. The two coordinate systems are:

- User coordinate system: User coordinate system is the coordinate system in which the job is defined, i.e., the 3MF coordinate system. The values configured in this space are respect to the 3MF content, which means that the layer ranges are defined before any dimensional compensation is applied.
- Physical coordinate system: The physical coordinate system refers to the physical position in the build unit in which the layer will be printed. This is especially valuable when a specific hardware component is to be tested and then the variation of the parameter to be modified must be done just in the specific position in which the hardware component is specified.

The user will define the different ranges of layers in any of the prior coordinate system. Each of the layer ranges will be defined by a start Z position, and an optional height value. If no height value is applied, then the level will end at the start Z position of the following level, or till the end of the job if there are no further levels. The DoE API guarantees that there is no overlap between level ranges when height attribute is specified, so that overlap of level definition has not to be handled by the estimator component. Also, in the case in which there are gaps between the defined levels, these portions must use the base printing profile configuration, so they must be treated as a virtually added level which is configured to use the parameters from the default printing profile selected in the job ticket.

The estimator component must determine the concrete Z start and Z end position of each of the levels along with the printing profile parameters to be used for each of the levels. Furthermore, it should allow to query these level ranges either in User coordinates or in Physical coordinates.

**For the examples used below we are assuming a 3D Printer printable box from 16920 to 396920 microns in Z, and a warming up height of 8000.*

Estimating level ranges in User Coordinates

The query of the level ranges in user coordinates is intended to be used during the processing of the job. For processing the job, it must be determined for each of the parts, which of the levels they belong to. The parts are defined in 3MF coordinate system (i.e., User Coordinates), therefore it is required the definition of the level ranges in User Coordinates to determine to which levels the part belong to. It may be the case that the part belongs to more than one level, in such case the part must be flagged as relying in different levels, and in the case that different render parameters are configured for each of the levels (e.g., layer thickness, xy resolution or dimensional compensations), it may be rejected as not supporting hybrid voxelization.

Here mainly we have two cases, depending on the coordinate system in which the levels are defined in the ticket:

- Levels defined in User Coordinates: This calculation is quite straight forward. The estimator must determine the start and end of the levels configured by the user and then add additional layer ranges for any potential gap. For instance, if the user defines two levels like:
    - Level 1: Start: 30000
    - Level 2: Start: 100000, Height: 200000.

  Then, estimator would compute the following layer ranges:
    - Layer Range 1: Start: 16920 – End: 30000; Default level configuration.
    - Layer Range 2: Start 30000 – End 100000; Level 1 configuration.
    - Layer Range 3: Start 100000 – End 300000; Level 2 configuration.
    - Layer Range 4: Start 300000 – End 396920 or End of job; Default level configuration.

- Levels defined in Physical Coordinates: In this case it is required a conversion of coordinate system. To perform this conversion, it is required to know the layer height that will be generated during the warming up, the scaling factors which are to be used for each of the levels, and the printable box Z coordinates. For example, if the user configures the following levels in physical coordinates:
    - Default level: Scaling Z: 1.02
    - Level 1: Start 30000; Scaling Z: 1.03
    - Level 2: Start: 100000, Height 20000: Scaling Z: 1.04

  In this case, the conversion must take into consideration the warming up height, so that the minimum coordinate from user coordinate (16920), must be mapped to the warming up height in physical coordinates (8000); and the scaling of each of the levels, so that each of the levels is properly converted:
    - Layer Range 1: Start: 16920 – End: 42214; Default level configuration.
    - Layer Range 2: Start 43813 – End 111774; Level 1 configuration.
    - Layer Range 3: Start 112689 – End 304996; Level 2 configuration.

    - Layer Range 4: Start 306920 – End 396920 or End of job; Default level configuration.
- It is worth to mention that as levels are defined in user coordinate and they may have different scaling configured, it may be the case that converted physical level ranges have some gap in between them, or even they may have some overlap. This is due to the case that in the case in which different scaling is used, in fact it is being done a conversion to a different coordinate system for each scaling factor.
- When a gap or an overlap is produced after the different scaling factors in the level, but the original levels in the user coordinates do not have those gaps or overlaps, the transition from one level to the other is done at the start coordinate of the level, either by extending the previous level up to that coordinate or to stop the for level at that coordinate.

Estimating level ranges in Physical Coordinates

The query of the level ranges in physical coordinates is intended to be used while printing, to determining the physical position of each of the levels, independently of the coordinate system in which they were defined.

- Levels defined in User Coordinates: In this case, it is required a conversion of coordinate system the conversion. To perform this conversion, it is required to know the layer height that will be generated during the warming up, the scaling which are to be used for each of the levels and the printable box Z coordinates. For example, if the use configures the following levels in physical coordinates. For example, if the following configuration is provided in User coordinates:
    - Default level: Scaling Z: 1.02
    - Level 1: Start 30000; Scaling Z: 1.03
    - Level 2: Start: 100000, Height 20000: Scaling Z: 1.04

  In this case, the conversion must take into consideration the warming up height, so that the minimum coordinate from user coordinate (16920), must be mapped to the warming up height in physical coordinates (8000); and the scaling of each of the levels, so that each of the levels is properly converted:
    - Layer Range 1: Start: 8000 – End: 17541; Default level configuration.
    - Layer Range 2: Start 15772 – End 87872; Level 1 configuration.
    - Layer Range 3: Start 86803 – End 294803; Level 2 configuration.
    - Layer Range 4: Start 292941 –End of job; Default level configuration.
- Levels defined in Physical Coordinate: In this case the estimation of the levels is direct, considering that the printing starts in the warming up height position and ends in the last layer of the job:
    - Level 1: Start: 30000
    - Level 2: Start: 100000, Height: 200000.

  Then, estimator would compute the following layer ranges:
    - Layer Range 1: Start: 8000 – End: 30000; Default level configuration.
    - Layer Range 2: Start 30000 – End 100000; Level 1 configuration.
    - Layer Range 3: Start 100000 – End 300000; Level 2 configuration.
    - Layer Range 4: Start 300000 –End of job; Default level configuration.

Disclosed by Sergio Gonzalez, Guiu Tio, Yngvar Rossow Sethne and Jordi Gonzalez Rogel, HP Inc.